

1 TITLE OF THE INVENTION

2 DISTANCE CORRECTING APPARATUS OF SURROUNDINGS MONITORING SYSTEM  
3 AND VANISHING POINT CORRECTING APPARATUS THEREOF.

4

5 BACKGROUND OF THE INVENTION

6 1. Field of the invention

7 The present invention relates to a distance correcting  
8 apparatus of a surroundings monitoring system for correcting  
9 distance information containing errors caused by a positional  
10 deviation of a stereoscopic camera and to a vanishing point  
11 correcting apparatus of the system.

12 2. Discussion of the background art

13 In recent years, a stereoscopic surrounding  
14 monitoring apparatus using a pair of left and right cameras, that  
15 is, a stereoscopic camera, having solid image element like CCD  
16 mounted on a vehicle and the like has been watched by concerned  
17 engineers. To detect a distance to an object, first respective  
18 pixel blocks having coincidence of brightness are found in left  
19 and right images (stereo matching), then distance data are  
20 calculated according to the principle of triangulation from a  
21 parallax, namely a relative deviation amount, between both pixel  
22 blocks. Consequently, in order to calculate distance data with  
23 high reliability, it is desirable that there exists no positional  
24 deviation other than the parallax in a pair of left and right  
25 images (stereo images). In actual world, however, the

1 stereoscopic camera has some amount of positional errors such  
2 as horizontal or vertical deviations (parallel deviations), a  
3 rotational deviation and the like, caused when the camera is  
4 installed on a vehicle and the like. Particularly, the horizontal  
5 deviation directly produces an error in an parallax and as a result  
6 the distance calculated based on the parallax differs from a real  
7 one.

8           With respect to this, Japanese Patent Application  
9 Laid-open No. Toku-Kai-Hei 10-307352 discloses a technology in  
10 which the positional deviation of the stereoscopic camera is  
11 corrected by applying a geometric transformation to the  
12 stereoscopic image. That is, when an initial adjustment of the  
13 positional deviation is made or when a readustment of the  
14 positional deviation generated by aged deterioration is made,  
15 a dedicated correction detecting device is connected with an image  
16 correction apparatus performing the affine transformation to  
17 calculate the difference of angle of view, a rotational deviation  
18 or a parallel deviation of the stereoscopic image obtained by  
19 imaging a specified pattern for adjustment and to establish  
20 (reestablish) parameters of the affine transformation according  
21 to the result of the calculation. The positional deviation is  
22 equivalently corrected by applying the affine transformation  
23 to images based on thus established affine parameters.

24           However, according to the aforesaid prior art, a  
25 special adjustment pattern is imaged by the stereoscopic camera

1 and the deviation is corrected based on the position of the pattern  
2 in images. Accordingly, when the correction is performed, it is  
3 necessary to interrupt the ordinary surroundings monitoring  
4 control and as a result this prior art is not suitable for a real  
5 time processing in which the monitoring control is carried out  
6 concurrently.

7  
8 SUMMARY OF THE INVENTION

9           It is an object of the present invention to provided  
10 a surroundings monitoring apparatus capable of correcting a  
11 parallax including errors, in particular, an error caused by  
12 horizontal deviation, in parallel with a surroundings monitoring  
13 control. It is further object of the present invention to provide  
14 a surroundings monitoring apparatus in which the accuracy of  
15 measuring distance is raised by using the corrected parallax.  
16 It is another object of the present invention to provide a  
17 surroundings monitoring apparatus in which, when three-  
18 dimensional information of an object is obtained using a vanishing  
19 point established beforehand, the accuracy of three-dimensional  
20 information of the object is raised by correcting this vanishing  
21 point.

22           To achieve these objects, a distance correcting  
23 apparatus of a surroundings monitoring system, comprises a stereo  
24 imaging means for stereoscopically taking a pair of images, a  
25 parallax calculating means for calculating a parallax based on

1 the pair of images, a distance calculating means for calculating  
2 a distance to an object based on the parallax and a parameter  
3 for correcting the distance, an approximation line calculating  
4 means for calculating a plurality of approximation lines  
5 extending in the distance direction in parallel with each other  
6 based on the images, a vanishing point calculating means for  
7 calculating a vanishing point of the images from a point of  
8 intersection of the approximation lines and a parameter  
9 correcting means for correcting the parameter based on the  
10 vanishing point.

#### 12 BRIEF DESCRIPTION OF THE DRAWINGS

13 Fig. 1 is a block diagram showing a construction of  
14 a stereoscopic type vehicle surroundings monitoring apparatus  
15 according to a first embodiment of the present invention;

16 Fig. 2 is a flowchart showing steps for correcting a  
17 parallax according to a first embodiment;

18 Fig. 3 is a flowchart continued from Fig. 2;

19 Fig. 4 is a flowchart showing steps for updating a  
20 parallax correction value DP according to a first embodiment;

21 Fig. 5 is a flowchart showing steps for updating a  
22 parallax correction value DP according to a second embodiment;

23 Fig. 6 is a block diagram showing a construction of  
24 a stereoscopic type vehicle surroundings monitoring apparatus  
25 according to a third embodiment of the present invention;

1           Fig. 7 is a flowchart showing steps for updating a  
2 parallax correction value SHFT1;

3           Fig. 8 is a diagram for explaining a calculated road  
4 height;

5           Fig. 9 is a diagram showing a relationship between a  
6 calculated road height and an actual road height;

7           Fig. 10 is a diagram for explaining a deviation caused  
8 by the difference between an actual road height and a calculated  
9 road height;

10          Fig. 11 is a diagram showing an example of a lane marker  
11 model;

12          Fig. 12 is a diagram for explaining lane marker edges  
13 of a reference image;

14          Fig. 13 is a diagram for explaining a calculation method  
15 of a vanishing point in a reference image;

16          Fig. 14 is a block diagram showing a construction of  
17 a stereoscopic type vehicle surroundings monitoring apparatus  
18 according to a fourth embodiment of the present invention;

19          Fig. 15 is a flowchart showing steps continued from  
20 Fig. 2 according to a fourth embodiment;

21          Fig. 16 is a diagram showing an example of an image  
22 of an indoor robot; and

23          Fig. 17 is a diagram showing an example of an image  
24 of a scenery in front of a railway rolling stock.

25

1 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

2           Fig. 1 is a block diagram of a stereoscopic type  
3 surroundings monitoring apparatus using an adjusting apparatus  
4 concerned with the embodiment. A stereoscopic camera for imaging  
5 a surrounding scenery of a vehicle is composed of a pair of  
6 cameras 1, 2 incorporating an image sensor such as CCD and the  
7 like and mounted in the vicinity of a room mirror of the vehicle.  
8 The cameras 1, 2 are mounted at a specified interval in the  
9 transversal direction of the vehicle. A main camera 1 is for  
10 obtaining a reference image data and is mounted on the right side  
11 when viewed in the traveling direction of the vehicle. On the  
12 other hand, a sub camera 2 is for obtaining a comparison image  
13 data and is mounted on the left side when viewed in the traveling  
14 direction of the vehicle. In a state of the cameras 1, 2  
15 synchronized with each other, analogue images outputted from the  
16 respective cameras 1, 2 are adjusted in an analogue interface  
17 3 so as to coincide with an input range of circuits at the latter  
18 stage. Further, the brightness balance of the images is adjusted  
19 in a gain control amplifier (GCA) 3a of the analogue interface  
20 3.

21           The analogue image signals adjusted in the analogue  
22 interface 3 are converted into digital images having a specified  
23 number of brightness graduations (for example, a grayscale of  
24 256 graduations) by an A/D converter 4. Respective data  
25 digitalized are subjected to an affine transformation in a

correction circuit 5. That is, the positional error of the stereoscopic cameras 1, 2 which is caused when the cameras 1, 2 are installed, generates deviations in stereoscopic images such as a rotational deviation, parallel deviation and the like. The error is equivalently corrected by applying the affine transformation to the images. In this specification, a term "affine transformation" is used for comprehensively naming a geometrical coordinate transformation including rotation, movement, enlargement and reduction of images. The correction circuit 5 applies a linear transformation expressed in Formula 1 to original images using four affine parameters  $\theta$ ,  $K$ , SHFTI and SHFTJ.

[Formula 1]

$$\begin{pmatrix} i' \\ j' \end{pmatrix} = K \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} i \\ j \end{pmatrix} + \begin{pmatrix} \text{SHFTI} \\ \text{SHFTJ} \end{pmatrix}$$

where  $(i, j)$  is coordinates of an original image and  $(i', j')$  is coordinates after transformation. Further, affine parameters SHFTI, SHFTJ mean a transference in a "i" direction (horizontal direction of image), a transference in a "j" direction (vertical direction of image), respectively. Further, affine parameters  $\theta$ ,  $K$  indicate a rotation by  $\theta$ , an enlargement (reduction in case of  $|K| < 1$ ) by  $K$  times, respectively. The affine transformation applied to the stereoscopic image assures a coincidence of the horizontal line in both images, which is essential for securing

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1 the accuracy of the stereo matching. The hardware constitution  
2 of the correction circuit 5 is described in Japanese Patent  
3 Application Laid-open No. Toku-Kai-Hei 10-307352. If necessary,  
4 the reference should be made to the disclosure.

5 Thus, through such image processing, the reference  
6 image data composed of 512 pixels horizontally and 200 pixels  
7 vertically are formed from output signals of the main camera 1.  
8 Further, the comparison image data having the same vertical length  
9 as the reference image and a larger horizontal length than the  
10 reference image, for example composed of 640 pixels horizontally  
11 and 200 pixels vertically, are formed from output signals of the  
12 sub camera 2. The coordinate system  $i$ - $j$  of image on a two-  
13 dimensional plane has an origin at the left below corner of the  
14 image, an  $i$  coordinate in the horizontal direction and a  $j$   
15 coordinate in the vertical direction. One unit of the coordinate  
16 system is one pixel. These reference image data and comparison  
17 image data are stored in an image data memory 7.

18 A stereo calculating circuit 6 calculates a parallax  
19  $d$  based on the reference image data and the comparison image data.  
20 Since one parallax  $d$  is produced from one pixel block constituted  
21 by  $4 \times 4$  pixels,  $128 \times 50$  parallax data are calculated per one  
22 reference image of a frame size. In calculating a parallax  $d_i$   
23 of a given pixel block in a reference image, first a corresponding  
24 pixel block of a comparison image is identified by searching an  
25 area having the same brightness as that given pixel block of the



1 reference image. As well known, the distance from the camera to  
2 an object projected in a stereo image is expressed as a parallax  
3 in the stereo image, namely a horizontal deviation amount between  
4 the reference and comparison images. Accordingly, in searching  
5 the comparison image, the search is performed on the same  
6 horizontal line (epipolar line) as a  $j$  coordinate of the reference  
7 image. In the stereo calculating circuit 6, the correlation is  
8 evaluated for every pixel block between the object pixel block  
9 and the searching pixel block while shifting a pixel one by one  
10 on the epipolar line (stereo matching).

11           The correlation between two pixel blocks can be  
12 evaluated for example using a city block distance which is one  
13 of well known evaluation methods. The stereo calculating circuit  
14 6 obtains a city block distance for every area (having the same  
15 area size as the object pixel block) existing on an epi-polar  
16 line and identifies an area whose city block distance is minimum  
17 as a correlation object of the object pixel block. The deviation  
18 amount between the object pixel block and the identified  
19 correlation object equals to a parallax  $d_i$ . The hardware  
20 constitution for calculating the city block distance and the  
21 method of determining the correlation object is disclosed in  
22 Japanese Patent Application No. Toku-Kai-Hei 5-114009. If  
23 necessary, the reference should be made to the disclosure. The  
24 parallax  $d$  calculated by the stereo calculating circuit 6 is  
25 stored in the distance data memory 8.

1           The micro-computer 9 or when seeing it from a functional  
2 point of view, a recognition section 10 which is a functional  
3 block, read image data of a reference image out from an image  
4 data memory 7 and recognizes an object (for example, a preceding  
5 vehicle and the like) projected in the reference image using a  
6 known image recognition technique. Further, the recognition  
7 section 10 calculates a distance Z to the object according to  
8 the following formula parameterizing a parallax d read out from  
9 the distance data memory 8.

10 [Formula 2]

$$11 \quad Z = KZH / (d - DP)$$

12 where KZH is a constant (base line length of camera / horizontal  
13 angle of view) and DP is a vanishing point parallax. In this  
14 embodiment, the vanishing point parallax DP is a parallax  
15 correction value (variable) which is calculated in a correction  
16 calculating section 13.

17           Further, the recognition section 10 performs a  
18 recognition of road configurations. Road configurations, that  
19 is, left and right lane markers (passing line, no passing line  
20 and the like) are expressed in a three-dimensional space as  
21 functions having parameters established so as to coincide with  
22 actual road configurations such as straight roads, curved roads  
23 or up-and-down roads. In this embodiment, a term "lane marker"  
24 represents a continuous white line-like marker drawn on a road,  
25 although the present invention is not limited to such lane markers.

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1 The method of calculating a lane marker model according to this  
2 embodiment will be described by reference to Fig. 12.

3 First, a white line edge Pedge, namely, a portion  
4 showing a large variation in brightness, is identified. The white  
5 line edge Pedge is searched separately for the left side and right  
6 side of a lane, respectively. A plurality of left white line edges  
7 Pedge1 and a plurality of right white line edges Pedge2 are  
8 identified respectively. Specifically, the brightness edges  
9 satisfying following three conditions are recognized as white  
10 line edges Pedge.

11 (Conditions of white line edge)

12 1. Brightness variation is larger than a specified value  
13 and pixels on the outer side (edge side of image) have a larger  
14 brightness than those on the inner side (central side of image).

15 The white line edges Pedge caused by the left and right  
16 lane markers are brightness edges at the boarder of lane marker  
17 and paved surface, as shown in Fig. 12.

18 2. With respect to candidates of the white line edge Pedge  
19 satisfying the condition 1, another edge exists outside of one  
20 edge on the same horizontal line as the candidates and brightness  
21 of pixels on the inner side is larger than that of pixels on the  
22 outer side.

23 Since the lane marker has a specified width, there is  
24 another boarder on the outer side of the white line edge Pedge.  
25 This condition is provided in view of the feature of lane marker.

1 3. With respect to pixel blocks including the white line  
2 edge Pedge satisfying the condition 1, a parallax d has been  
3 calculated.

4 If there is no parallax d where a white line edge exists,  
5 the white line edge Pedge is not effective for recognizing a road  
6 configuration.

7 The recognition section 10 calculates coordinates (X,  
8 Y, Z) in real space by substituting coordinates (i, j) and its  
9 parallax d for every identified white line edge Pedge into the  
10 following Formula 3 and Formula 4.

11 [Formula 3]

$$12 \quad Y = CAH - Z(JV - j)PWV$$

13  
14 [Formula 4]

$$15 \quad X = r/2 + Z(IV - i)PWH$$

16 where CAH is an installation height of cameras 1, 2; r is an  
17 interval between cameras 1, 2; PWV and PWH are a vertical and  
18 horizontal angle of view per one pixel, respectively; IV and JV  
19 are an i coordinate and j coordinate of a vanishing point V  
20 established, respectively.

21 Further, the coordinate system in real space comprises  
22 an origin placed on the road surface immediately beneath of the  
23 center of the cameras 1, 2, X axis extending in the widthwise  
24 direction of the vehicle, Y axis extending in the vertical  
25 direction of the vehicle and Z axis extending in the longitudinal

1 direction of the vehicle. When the coordinates (i, j) and the  
2 parallax d of an object (a preceding vehicle, a solid object,  
3 a road and the like) projected on the image are identified, the  
4 coordinates (X, Y, Z) of the object in real space can be  
5 unconditionally identified according to the transformation  
6 formulas shown in Formulas 2 through 4.

7 A lane marker model is identified based on the  
8 coordinates (X, Y, Z) of thus identified respective white line  
9 edges Pedge in real space. The lane marker model is prepared in  
10 such a manner that approximation lines are obtained for every  
11 specified interval with respect to each of the left and right  
12 white line edges Pedge1, Pedge2 within a recognition range (for  
13 example, a range of 84 meters away in front of the vehicle from  
14 camera) and thus obtained approximation lines are combined like  
15 broken lines. Fig. 11 shows an example of a lane marker model  
16 in which the recognition range is divided into seven segments  
17 and the left and right white line edges Pedge1, Pedge2 for each  
18 segment are approximated to a linear equation expressed as follows  
19 according to the least square method.

20 [Formula 5]

21 (Left lane marker model L)

22 
$$X = a_L \cdot Z + b_L$$

23 
$$Y = c_L \cdot Z + d_L$$

24 (Right lane marker model R)

25 
$$X = a_R \cdot Z + b_R$$

1 
$$Y = c_R \cdot Z + d_R$$

2 These lane marker models L, R are constituted by a curve  
3 function ( $X = f(Z)$ ) for expressing a curvature of road and a  
4 gradient function ( $Y = f(Z)$ ) for expressing a gradient or  
5 condition of unevenness of road. Accordingly, the three-  
6 dimensional feature of the road in real space can be expressed  
7 by the left and right lane marker models L, R. Respective white  
8 line edges and left and right lane marker models L, R calculated  
9 in the recognition section 10 are transmitted to a correction  
10 calculating section 13.

11 The recognition section 10 actuates a warning device  
12 11 such as a display monitor or a speaker when it is judged that  
13 a warning is needed based on the result of recognition of preceding  
14 vehicles or road configurations. Further, the recognition  
15 section 10 controls a control device 12 to carry out miscellaneous  
16 vehicle controls such as engine output control, shift control  
17 of automatic transmission, brake control and the like.

18 Next, the method of correcting distance information  
19 according to the embodiment will be briefly described by reference  
20 to Fig. 8.

21 Assuming that the Z axis of the vehicle is always  
22 horizontal with respect to an even road without up-and down, that  
23 is, there is no pitching of the vehicle, the height Y of the road  
24 surface is expressed by a line Lr with a gradient a ( $a = 0$ ). This  
25 line Lr is called an actual road surface height. Letting

1 coordinates of a point p1 (hereinafter referred to as a road  
 2 surface point) projected on the reference image be (i1, j1) and  
 3 letting its parallax be d1, the position of this road surface  
 4 point p1 in real space is identified unconditionally as  
 5 coordinates (x1, y1, z1).

6 [Formula 6]

$$7 \quad z1 = KZH / (d1 - DP)$$

8

9 [Formula 7]

$$10 \quad y1 = CAH - z1(JV - j1)PWV$$

11

12 [Formula 8]

$$13 \quad x1 = r/2 + z1(IV - i1)PWH$$

14

15 In case where a flat road without up-and-down horizontally exists,  
 16 if the distance z1 calculated from the parallax d1 includes no  
 17 error, the height y1 calculated from Formula 7 should be 0. That  
 18 is, if the value of the distance z1 is identical to an actually  
 19 measured value, a line Lr' (hereinafter, referred to as a  
 20 calculated road surface height) connecting an origin and the road  
 21 surface point p1 agrees with the actual road surface height.  
 22 Namely, the gradient of the calculated road surface height Lr'  
 23 becomes 0. On the other hand, in case where the value of the  
 24 distance z1 contains errors and differs from the actually measure  
 25 value, the height y1 calculated from Formula 7 is not equal to

1 0, the calculated road height  $Lr'$  having a specified gradient  
2  $a'$  ( $a' = y1/z1 \neq 0$ ).

The reason why the calculated height  $y_1$  is not equal to 0 is that the parallax  $d_1$  containing errors due to the effect of the horizontal deviation of the stereoscopic camera is calculated and these errors are not properly offset by the vanishing point parallax  $DP$  (corresponding to a parallax correction value). Hence, if a deviation amount of the gradient  $a'$  ( $a' \neq 0$ ) of the calculated road surface height  $Lr'$  with respect to the gradient  $a$  of the actual road surface height  $Lr$  is known, a deviation amount  $\Delta DP$  between the proper value of the vanishing point parallax  $DP$  and the current value can be calculated.

3 First, in case where the vanishing point parallax DP  
4 is an optimum value enough to be able to completely offset the  
5 errors, the gradient value of the calculated road surface height  
6  $Lr'$  (agrees with the the gradient of the actual road surface height  
7  $Lr$ ) is  $a$ . Accordingly, the gradient  $a$  is expressed based on Formula  
8 6 and Formula 7 which have been described as follows:

9 [Formula 9]

$$a = \frac{y1}{z1} = \frac{CAH}{KZH} (d1 - DP) - (JV - j1) PWV$$

On the other hand, in case where the vanishing point  
parallax is a value  $DP'$  which deviates from the proper value  $DP$ ,  
the gradient  $a'$  of the calculated road surface height  $Lr'$  is



1 expressed in the following formula:

2 [Formula 10]

$$\begin{aligned} 3 \quad a' &= \frac{y_l}{z_l} \\ 4 \quad &= \frac{CAH}{KZH} (d_l - DP') - (JV - j_l) PWV \\ 5 \end{aligned}$$

6 Eliminating d, j based on the formulas 9 and 10,  
7 following formula is obtained:

8 [Formula 11]

$$9 \quad a - a' = \frac{CAH}{KZH} (DP' - DP)$$

11 Transforming the formula 11 to obtain  $DP - DP'$ ,  
12 that is, the deviation amount  $\Delta DP$  of the vanishing point parallax:

13 [Formula 12]

$$\begin{aligned} 14 \quad \Delta DP &= DP - DP' \\ 15 \quad &= \frac{KZH}{CAH} (a' - a) \\ 16 \end{aligned}$$

17 The gradient a of the actual road height  $L_r$  is 0. On  
18 the other hand, the gradient  $a'$  of the calculated road height  
19  $L_r'$  can be identified based on the parameter c of the lane marker  
20 model L, R ( $Y = c \cdot Z + d$ ) calculated in the recognition section.  
21 Similarly to the gradient  $a'$  of the calculated road surface height  
22  $L_r'$ , when the horizontal deviation of the stereoscopic camera  
23 exists, the error caused by the deviation effects on the lane  
24 marker model L, R. Hence, letting the mean value of parameters  
25  $c_L, c_R$  of the left and right lane marker model L, R up to a

1 predetermined distance (for example a range from 0 to Z2) be C,  
2 it is possible to regard this value C as a gradient a' of the  
3 calculated road surface height Lr'. Further, substituting a =  
4 0, a' = C into the formula 12, the deviation amount  $\Delta DP$  of the  
5 vanishing point parallax is expressed by the following formula  
6 finally:

7 [Formula 13]

$$\Delta DP = \frac{KZH}{CAH} C$$

10 As seen from the formula 13, the result of multiplying  
11 the parameter C by a constant (KZH/CAH) is the deviation amount  
12  $\Delta DP$  of the vanishing point parallax. Hence, by adding the  
13 deviation amount  $\Delta DP$  to the vanishing point parallax DP, the  
14 calculated road surface height Lr' can be made identical to the  
15 actual road height Lr (a' = a = 0. That is, the error of the parallax  
16 d caused by the horizontal deviation of the stereoscopic camera  
17 can be eliminated by using the vanishing point parallax DP  
18 properly established based on the deviation amount  $\Delta DP$  calculated  
19 according to the formula 13. As a result, even in a case where  
20 a horizontal deviation of the stereoscopic camera exists, an  
21 accurate distance Z can be calculated by properly establishing  
22 the vanishing point parallax DP which is a parallax correction  
23 value.

24 The description above is based on a premise that the  
25 flat road without up-and-down is always horizontal with respect

1 to Z-axis. However, in practice, an actual road surface height  
2 L of the flat road does not always agree with Z-axis due to the  
3 affect of the pitching motion of the own vehicle. For example,  
4 when the own vehicle directs upward (sky side), the gradient a  
5 of the actual road surface height Lr becomes a negative value  
6 and when the own vehicle directs downward (ground side), the  
7 gradient a of the actual road surface height Lr becomes a positive  
8 value. When the gradient a of the actual road height Lr is rendered  
9 to be 0 as mentioned before, the deviation amount  $\Delta DP$  itself has  
10 an error due to the effect of pitching. From the view point of  
11 improving the accuracy of a calculated distance, it is necessary  
12 to properly calculate the gradient a of the actual road surface  
13 height Lr.

14 "A vanishing point" is identified based on a two-  
15 dimensional(i-j plane) positional information of the left and  
16 right lane markers in the reference image and then a gradient  
17 a of the actual road surface height Lr is calculated from this  
18 "vanishing point". Here, the term "vanishing point" is defined  
19 to be an infinitely far point (infinite point), that is, a point  
20 where all parallel lines extending in the depth (distance)  
21 direction converge at the infinite far image. For example, when  
22 a rectangular parallelepiped disposed in a three-dimensional  
23 space is mapped through a camera on a two-dimensional plane, the  
24 parallel lines constituting the rectangular parallelepiped  
25 always meet together at a point. This point of intersection is

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1 "a vanishing point". In the vehicle surroundings monitoring  
2 apparatus for imaging the frontal scene, this example corresponds  
3 to a case where the left and right lane markers on respective  
4 road sides run ahead in parallel with each other in the depth  
5 (distance) direction of the image. Since the left and right lane  
6 markers are in parallel with each other, the left and right lane  
7 markers in the picture image are approximated to straight lines  
8 respectively, letting the intersection of these lines be a  
9 vanishing point V2d (IV2D, JV2D).

10 Specifically, as shown in Fig. 13, a plurality of left  
11 white line edges Pedg1 are approximated to a straight line to  
12 obtain an approximation line L1 and similarly a plurality of right  
13 white line edges Pedg2 are approximated to a straight line to  
14 obtain an approximation line L2. In order to raise the accuracy  
15 in calculating the vanishing point JV2D, it is preferable that  
16 only the white line edges within a specified range of distance  
17 (for example, 0 to Z2) are used for calculating the approximation  
18 line. The range of distance, if it is too short, the accuracy  
19 of the approximation lines L1, L2 and if it is too long, the amount  
20 of calculations increases or there is a decreasing chance of the  
21 lane marker projected on the line, that is, it is difficult to  
22 create the condition of lane marker suitable for calculating the  
23 vanishing point JV2D. The intersection of these approximation  
24 lines L1, L2 is a vanishing point V2d. The gradient  $a$  of the actual  
25 road surface height  $L_r$  can be identified if the  $j$ -coordinate JV2D

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1 is known. Accordingly, in the description hereinafter, the  
2 j-coordinate JV2D of the vanishing point V2d is referred to as  
3 "actual vanishing point" for the purpose of discriminating from  
4 the established vanishing point JV.

5 Fig. 9 is a diagram showing the relationship between  
6 the actual road surface height  $L_r$  and the calculated road surface  
7 height  $L_r'$ . The stereoscopic camera is mounted on the vehicle  
8 in such a manner that the vanishing line  $L_v$  connecting the  
9 installation height CAH of the camera and the actual vanishing  
10 point JV2D is in parallel with the actual road surface height  
11  $L_r$ . In case where the own vehicle generates pitchings, the  
12 gradient of the actual road surface height  $L_r$  varies and at the  
13 same time the gradient of the vanishing line  $L_v$  also varies. That  
14 is, regardless of the existence or nonexistence of the pitching  
15 of the own vehicle, the gradient of the actual road surface height  
16  $L_r$  always agrees with that of the vanishing line  $L_v$  (both gradients  
17 are  $a$ ). That is to say, even in case where the vehicle has a pitching  
18 motion, the vanishing line  $L_v$  is always in parallel with the actual  
19 road surface height  $L_r$ . Consequently, the gradient of the actual  
20 road surface height  $L_r$  can be identified by obtaining the gradient  
21  $a$  of the vanishing line  $L_v$ . If this gradient  $a$  is known, the  
22 vanishing point parallax DP can be calculated by transforming  
23 the formula as follows.

24 First, after substituting the vanishing point JV2D  
25 into a variable  $j$  of the formula 3, obtaining the gradient  $(Y/Z)$

1 on Z-Y plane:

2 [Formula 14]

$$3 \quad a = (JV2D - JV)PWV$$

4 As seen from the formula, if the actual vanishing point  
5 JV2D is identified, the gradient a (corresponding to the gradient  
6 of the actual road surface Lr) height of the vanishing line Lv  
7 is identified unconditionally.

8 Substituting the formula 14 into the formula 12,  
9 finally the following formula can be obtained:

10 [Formula 15]

$$11 \quad \Delta DP = \frac{KZH}{CAH} C - \frac{KZH}{CAH} (JV2D - JV)PWV$$

12  
13 The formula 15 is obtained by subtracting a portion  
14 affected by the pitching as a correction term from the formula  
15 13. The correction term is obtained by multiplying the product  
16 of substituting the established vanishing point JV from the actual  
17 vanishing point JV2D by a predetermined constant KZH/CAH.  
18 Accordingly, if the current value of the vanishing point parallax  
19 DP is added by the deviation amount  $\Delta DP$ , regardless of the  
20 existence or nonexistence of pitching of the own vehicle, the  
21 gradient a' of the calculated road surface height Lr' always  
22 agrees with the gradient a of the actual road surface height Lr.  
23 This means that the error caused by the horizontal deviation of  
24 the stereoscopic camera is offset by the vanishing point parallax  
25 DP and the distance Z is calculated as being actually measured.

1 The effect of pitching of the own vehicle exerts not only on the  
2 gradient  $a$  of the vanishing line  $L_v$  (and the actual road surface  
3 height  $L_r$ ) but also on the gradient  $a'$  of the calculated road  
4 surface height  $L_r'$ . However, the deviation amount  $\Delta DP$  is  
5 calculated such that the effect of pitching with respect to the  
6 gradient  $a$  and the effect of pitching with respect to the gradient  
7  $a'$  are mutually offset (refer to the formula 12). Accordingly,  
8 an accurate deviation amount  $\Delta DP$

9 can be calculated without being affected by pitching of the  
10 vehicle.

11 Next, the detailed description of the parallax  
12 correction according to this embodiment will be made by reference  
13 to flowcharts shown in Fig. 2 and Fig. 3.

14 The correction calculating section 13 updates the  
15 value of the vanishing point parallax  $DP$  according to a series  
16 of steps and this value is fed back to the recognition section  
17 10. The flowcharts are executed repeatedly per cycle.

18 First, at a step 1, the correction calculating section  
19 13 reads white line edges  $P_{edge}$  and lane marker models  $L, R$   
20 calculated in the recognition section 10 of a reference image.  
21 Next, at steps 2 through 6, it is evaluated whether or not the  
22 reference image is in a suitable condition for calculating the  
23 vanishing point  $JV2D$ . First, at a step 2, it is judged whether  
24 or not the left and right lane markers exist in the reference  
25 image which is an object of calculating the vanishing point  $JV2D$ .

1 That is, this can be judged by investigating whether or not the  
2 left and right lane marker models L, R have been calculated in  
3 the recognition section 10. Further, this may be judged by  
4 investigating whether or not the left white line edges Pedge1  
5 and the right white line edges Pedge2 have been calculated. At  
6 the step 2, in case where the judgment is negative, that is, in  
7 case where the left and right lane markers exist nowhere, since  
8 mutually parallel lines have not extracted, the vanishing point  
9 JV2D can be calculated. Hence, in order to maintain the safety  
10 of the control, the program goes to RETURN without changing the  
11 current value of the vanishing point parallax DP and the execution  
12 of this flowchart in the present cycle finishes. On the other  
13 hand, at the step 2, in case where the judgment is positive, the  
14 program goes to a step 3.

15 At the step 3, the reliability of the left and right  
16 lane markers are verified. Specifically, following two things  
17 are evaluated.

18 1. In case where the difference between the position of  
19 the lane marker in the previous cycle and the position of the  
20 lane marker in the present cycle is greater than a specified value,  
21 it is judged that the lane marker has a low reliability.  
22 Specifically, in case where the position of the white line edge  
23 Pedge detected in the previous cycle largely deviates from the  
24 position of the white line edge Pedge detected in the present  
25 cycle, the lane marker is judged to have a low reliability.



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1     2.            It is verified how far the lane marker extends in the  
2     depth direction of an image. The lane marker has at least some  
3     extent of length. Accordingly, taking the shift of the lane  
4     marker between frames into consideration, in case where the lane  
5     marker does not extend longer than a specified length, it is judged  
6     that this lane marker has a low reliability.

7            After that, at a step 4, it is judged whether or not  
8     the lane marker is reliable and only when it is judged to be  
9     reliable, the program goes to a step 5. On the other hand, when  
10    it is judged that the lane marker can not be relied, the program  
11    goes to RETURN without changing the value of the vanishing point  
12    parallax DP.

13           At the step 5, the linearity of the lane marker is  
14    evaluated. In order to calculate an accurate vanishing point JV2D,  
15    it is necessary that the left and right lane markers extend in  
16    line. That is, it is impossible to calculate an accurate vanishing  
17    point JV2D from curved lane markers. Hence, only in case where  
18    it is judged at a step 6 that the lane marker is a straight line,  
19    The program goes to a step 7 and otherwise the program goes to  
20    RETURN without changing the value of the vanishing point parallax  
21    DP.

22           The linearity of the lane marker can be evaluated for  
23    example based on a lane marker model (curve function  $X = f(Z)$ )  
24    calculated in the recognition section 10. Describing by reference  
25    to Fig. 11, first a gradient  $A_1$  (mean value of gradients  $a_L$ ,  $a_R$

1 obtaining the gradient  $a$  of the vanishing point  $L_v$  just means  
2 calculating a gradient  $a$  of the actual road surface height.

3 Next, at a step 10, a gradient  $a'$  of the calculated  
4 road surface height  $L_r'$  is calculated. As mentioned before, the  
5 gradient  $a'$  is a parameter  $C$  calculated from the left and right  
6 lane marker models  $L, R$ .

7 At a step 11, the correction of parallax, namely, an  
8 up-dating of the vanishing point parallax  $DP$  is performed. Fig.  
9 4 is a flowchart showing steps for up-dating the vanishing point  
10 parallax  $DP$ . First, at a step 21, a deviation amount  $\Delta DP$  is  
11 calculated by substituting the parameter  $C$  and the vanishing point  
12  $JV2D$  into the formula 15.

13 At a step following the step 21, in order to secure  
14 the safety of control, the up-dating process of the vanishing  
15 point parallax  $DP$  is performed using a proportional control. That  
16 is, the value of the vanishing point parallax  $DP$  is up-dated by  
17 adding an value the deviation amount  $\Delta DP$  calculated at the step  
18 21 and multiplied by a proportional constant  $k(0 < k < 1)$  to the  
19 present value of the vanishing point parallax  $DP$ . Further, at  
20 a step 23, the up-dated vanishing point parallax  $DP$  is outputted  
21 to the recognition section 10 and the execution of this flowchart  
22 in the present cycle finishes.

23 The aforesaid flowchart is carried out in consecutive  
24 cycles. Therefore, even if such a situation that the vanishing  
25 point parallax  $DP$  is out of a proper value, occurs, the vanishing

1 of left and right lane markers L, R, respectively) of the curve  
2 function within a specified distance range (for example 0 to Z2)  
3 on Z-X plane, is calculated. The gradient A1 is a mean value of  
4 a gradient a1 in the first segment and a gradient a2 in the second  
5 segment. Next, a gradient A2 of the curve function within a  
6 specified distance range located ahead (for example Z2 to Z4)  
7 is calculated. The gradient A2 is is a mean value of a gradient  
8 a3 in the third segment and a gradient a4 in the fourth segment.  
9 Then, a difference (absolute value) between the gradients A1 and  
10 A2 is obtained. If the difference is smaller than a threshold  
11 value, it is judged that the lane marker is a straight line.

12 Steps after the step 7 are related to an up-dating of  
13 the vanishing point parallax DP. First, at the step 7, an  
14 approximation line L1 of a plurality of left white line edges  
15 Pedge1 existing within a specified range (for example, 0 to Z2)  
16 is calculated according to the least square method (refer to Fig.  
17 13). Similarly, an approximation line L2 of a plurality of left  
18 white line edges Pedge2 existing within that range is calculated  
19 according to the least square method.

20 At a step 8 following the step 7, as shown in Fig. 13,  
21 an point of intersection of the approximation lines L1, L2 is  
22 determined to calculate the vanishing point JV2D of the reference  
23 image. Further, at a step 9, a gradient a of the vanishing line  
24 Lv is calculated by substituting the vanishing point JV2D  
25 calculated at the step 8 into the formula 14. As described above,

1 point parallax DP gradually comes close to a proper value by  
2 carrying the flowchart out repeatedly. Hence, since the error  
3 of the distance  $Z$  caused by the horizontal deviation of the  
4 stereoscopic camera is gradually offset, the gradient  $a'$  of the  
5 calculated road surface  $Lr'$  converges to the gradient  $a$  of the  
6 actual road surface height  $Lr$ .

7           According to the steps described above, the  
8 optimization of the vanishing point parallax DP proceeds in  
9 parallel with the normal monitoring control and even in case where  
10 the horizontal deviation of the stereoscopic camera occurs, the  
11 distance can be always calculated accurately. Accordingly, even  
12 in case where the position of the stereoscopic camera is changed  
13 from the initial position by aged deterioration of the camera  
14 or shocks applied to thereto, highly reliable distance  
15 information can be obtained stably. The highly reliable distance  
16 information provides surroundings monitorings with a  
17 reliability.

18           Further, the left and right lane markers existing on  
19 both sides of the road are used as mutually parallel lines  
20 extending in the depth direction and needed for the calculation  
21 of the vanishing point JV2D of the reference image. In this  
22 embodiment, it is judged whether or not the lane marker is suitable  
23 for calculating the vanishing point JV2D by evaluating the  
24 linearity of the lane marker or the positional relationship of  
25 the lane marker between frames. Further, only when it is judged

1 that the lane marker is suitable, the value of the vanishing point  
2 parallax DP or the parallax correction value is changed. Hence,  
3 since an inappropriate vanishing point JV2D can be prevented from  
4 being calculated, this providing further stable, highly reliable  
5 distance information.

6 In the above description, the updating of the vanishing  
7 point parallax is performed by the proportional control, however,  
8 the updating may be performed by the statistic control. For  
9 example, preparing a histogram composed of 1000 samples of the  
10 deviation amount  $\Delta DP$  of the vanishing point parallax, a most  
11 frequently observed value may be used as a deviation amount  $\Delta$   
12 DP. This up-dating process according to the statistical control  
13 can be can be applied to a second, third, and fourth embodiments.  
14 (Second embodiment)

15 According to the second embodiment, the parallax  
16 correction value DP is updated based on the comparison  
17 relationship between the gradient  $a$  of the actual road surface  
18 height  $L_r$  (that is, gradient  $a$  of the vanishing line  $L_v$ ) and the  
19 gradient  $a'$  (that is, the parameter  $C$  identified from the lane  
20 marker models  $L, R$ ) of the calculated road surface height  $L_r'$ .  
21 The steps of up-dating are the same as those shown in the  
22 flowcharts of Figs. 2 and 3. A portion different from the first  
23 embodiment is the step 11 of Fig. 3, that is, a part where the  
24 distance calculation parameter is updated.

25 Fig. 5 is a flowchart showing up-dating steps of the

1 parallax correction value DP according to the second embodiment.  
2 First, at a step 31, it is judged whether or not the product of  
3 subtracting the gradient  $a$  of the actual road surface height  $L_r$   
4 from the gradient  $a'$  of the calculated road surface height  $L_r'$ ,  
5 is larger than a positive threshold value TH. In case where the  
6 positive judgment (YES) is made at the step 31, the program goes  
7 to a step 34 where a specified value  $\alpha$  is added to the present  
8 value of the vanishing point parallax DP and at a step 36 a larger  
9 vanishing point parallax DP than a previous one is outputted to  
10 the recognition section 10. On the other hand, in case of NO at  
11 the step 31, the program goes to a step 32.

12           At the step 32, it is judged whether or not the  
13 subtraction of the gradient  $a$  from the gradient  $a'$  is smaller  
14 than a negative threshold value  $-TH$ . In case of Yes at the step  
15 32, at a step 34, the specified  $\alpha$  is reduced from the present  
16 value of the vanishing point parallax DP. Accordingly, at a step  
17 36, a smaller vanishing point parallax DP than the previous one  
18 is outputted to the recognition section 10. On the other hand,  
19 in case of NO at the step 32, that is, in case where the subtraction  
20  $a'-a$  is within a range from the negative threshold value  $-TH$  to  
21 the positive threshold value TH, the value DP is not changed based  
22 on the judgment that the vanishing point parallax DP is proper  
23 to maintain the control stability.

24           The relationship between the difference of the  
25 gradient  $a'$  of the calculated road surface height  $L_r'$  from the

1 gradient  $a$  of the actual road surface height  $L_r$  and the distance  
2  $Z$ , will be described by reference to Fig. 10.

3           Letting the distance to a road surface point  $P_1$  be  $z_1$ ,  
4 and letting the gradient of the actual road surface height  $L_r$   
5 passing through the road surface point  $P_1$  be  $a$ , when the distance  
6  $z_1'$  (containing an error) is calculated, a road surface point  
7  $P_1'$  on  $Z$ - $X$  plane appears on a line  $m$  connecting the installation  
8 height of the camera  $CAH$  and the original road surface point  $P_1$ .  
9 Accordingly, it is understood that as the calculated distance  
10  $z_1'$  becomes smaller than the actual distance  $z_1$ , the gradient  
11  $a'$  of the calculated road surface height  $L_r'$  becomes larger than  
12 the gradient  $a$  of the actual road surface height  $L_r$ . From this  
13 point of view, in case of  $a' > a$ , the calculated distance  $z_1'$  should  
14 be adjusted so as to increase and for that purpose the value of  
15 the vanishing point parallax  $DP$  should be increased (see the  
16 formula 2). Inversely, in case of  $a' < a$ , the calculated distance  
17  $z_1'$  should be adjusted to become small and for this purpose the  
18 value of the vanishing point parallax  $DP$  should be decreased.

19           Even in case where the vanishing point parallax  $DP$   
20 is not proper, that value gradually comes close to the proper  
21 value by carrying out the aforesaid flowchart in respective cycles.  
22 Hence, since the error of the distance  $Z$  caused by the horizontal  
23 deviation of the stereoscopic camera is gradually offset by the  
24 vanishing point parallax  $DP$ , the gradient  $a'$  of the calculated  
25 road surface height  $L_r'$  converges to the gradient  $a$  of the actual

1 road surface height  $L_r$ . As a result, also in this embodiment,  
2 a highly accurate distance can be obtained stably. Further, as  
3 a result of performing the monitoring control based on thus  
4 obtained distance, the reliability of the vehicle surroundings  
5 monitoring can be enhanced.

6 (Third embodiment)

7 The feature of this embodiment is that an affine  
8 parameter SHFT1 (shift in horizontal direction) in the affine  
9 transformation is updated according to the difference between  
10 the gradient  $a'$  of the calculated road surface height  $L_r'$  and  
11 the gradient  $a$  of the actual road surface height  $L_r$ .

12 Fig. 6 is a block diagram showing the construction of  
13 a stereoscopic type vehicle surroundings monitoring apparatus  
14 according to the third embodiment. The block diagram is the same  
15 as that of Fig. 1 except for that the affine parameter SHFT1  
16 calculated in the correction calculating section 13 is fed back  
17 to the correction circuit 5. Therefore, the components of the  
18 block diagram which are identical in both embodiments are denoted  
19 by identical reference numbers and are not described in detail.

20 The steps of updating the affine parameter SHFT1 are  
21 the same as the flowcharts shown in Figs. 2 and 3 in the first  
22 embodiment. What differs from the first embodiment is a step 11  
23 of Fig. 3 concerning the updating of parameters for calculating  
24 the distance.

25 Fig. 7 is a flowchart showing steps for up-dating an



1 affine parameter SHFT1 (parallax correction value) which  
2 represents the shift in the horizontal direction. First, at a  
3 step 41, it is judged whether or not the product of subtracting  
4 the gradient  $a$  of the actual road surface height  $L_r$  from the  
5 gradient  $a'$  of the calculated road surface height  $L_r'$ , is larger  
6 than a positive threshold value TH. In case where the positive  
7 judgment (YES) is made at the step 41, the program goes to a step  
8 44 where a specified value  $\beta$  is subtracted from the present value  
9 of the affine parameter SHFT1 and at a step 46 a smaller affine  
10 parameter SHFT1 than a previous one is outputted to the correction  
11 circuit 5. On the other hand, in case of NO at the step 41, the  
12 program goes to a step 42.

13           At the step 42, it is judged whether or not the  
14 subtraction  $a' - a$  is smaller than a negative threshold value  $-TH$ .  
15 If the judgment is YES at the step 42, the specified value  $\beta$  is  
16 added to the present value of the affine parameter SHFT1 at a  
17 step 45 and a larger affine parameter SHFT1 than a previous one  
18 is outputted to the correction circuit 5 (step 46). On the other  
19 hand, if the judgment is NO at the step 42, that is, if the  
20 subtraction  $a' - a$  is within a range from the negative threshold  
21 value  $-TH$  to the positive threshold value TH, it is judged that  
22 the affine parameter SHFT1 is proper to maintain the control  
23 stability and this value is not changed.

24           As described in the second embodiment, in case of  $a' > a$ ,  
25 the calculated distance  $z_1'$  should be adjusted so as to increase,

1 in other words, the parallax  $d$  should be reduced. For that purpose,  
2 the value of the affine parameter SHFT1 should be established  
3 to be smaller than the previous one. That is, the affine parameter  
4 SHFT1 is updated such that the shift amount in the horizontal  
5 direction becomes small. Inversely, in case of  $a' < a$ , the  
6 calculated distance  $z1'$  should be adjusted to become small, in  
7 other words, the parallax  $d$  should be increased. For this purpose,  
8 the value of the affine parameter SHFT1 should be established  
9 to be larger than the previous one. That is, the affine parameter  
10 SHFT1 is up-dated such that the shift amount in the horizontal  
11 direction becomes large.

12 As described before, the feedback adjustment of the  
13 affine parameter SHFT1 (representing the shift in the horizontal  
14 direction) is made in parallel with the monitoring control. As  
15 a result, even in case where the horizontal deviation of the  
16 stereoscopic camera occurs, the affect of the deviation is offset  
17 by the affine parameter SHFT1, thereby an accurate parallax  $d$   
18 can be obtained. As a result, highly accurate distance information  
19 can be obtained, whereby the reliability of the vehicle  
20 surroundings monitoring can be enhanced.

21 (Fourth embodiment)

22 This embodiment relates to the method of regulating  
23 the established vanishing point  $V$  (IV, JV) used in the  
24 transformation formulas 3 and 4 for calculating coordinates (X,  
25 Y) showing the position of an object by utilizing the vanishing

1 point V2d (IV2D, JV2D) which is shown in Fig. 13.

2 Fig. 14 is a block diagram showing a stereoscopic type  
3 vehicle surroundings monitoring apparatus according to a fourth  
4 embodiment. In the correction calculating section 13, the  
5 established vanishing point V (IV, JV) is updated based on the  
6 vanishing point V2d (IV2D, JV2D) in the reference image and the  
7 calculated vanishing point IV, JV is outputted to the recognition  
8 section 10. Except for this section, the block diagram is  
9 identical to that of Fig. 1. Therefore, identical reference  
10 numbers denoted  
11 in both embodiments are not described in detail.

12 Next, steps for updating the established vanishing  
13 point IV, JV will be described. First, according to the steps  
14 from the step 1 to the step 6 shown in the flowchart of Fig. 2,  
15 it is judged whether or not the reference image is in a condition  
16 suitable for calculating the vanishing point J2d (IV2D, JV2D).

17 Fig. 15 is a flowchart according to this embodiment  
18 continued from Fig. 2 and related to the updating process of the  
19 established vanishing point V (IV, JV). First, at a step 51,  
20 an approximation line L1 of a plurality of left white line edges  
21 Pedge1 existing within a specified distance range (for example,  
22 0 to Z2) is calculated by the least square method (see Fig. 13).  
23 Also, in the same manner, at the step 51, an approximation line  
24 L2 of a plurality of right white line edges Pedge2 existing within  
25 the distance range is calculated by the least square method. After

1 that, the program goes to a step 52 where a point of intersection  
 2 of both approximation lines L1, L2, that is, a vanishing point  
 3 J2d (IV2D, JV2D) of the reference image is calculated.

4 At a step 53 following the step 52, the established  
 5 vanishing point V (IV, JV) which is employed in the formulas 3  
 6 and 4, is updated. First, the present value of an i coordinate  
 7 value IV of the established vanishing point V is compared with  
 8 an i coordinate value IV2D calculated at the step 52 and based  
 9 on the result of the comparison, the vanishing point IV is updated  
 10 by the following proportional control:

11 [Updating of vanishing point IV]

12 In case of  $IV - IV2D > TH$   $IV \leftarrow IV - \gamma$

13 In case of  $IV - IV2D < -TH$   $IV \leftarrow IV + \gamma$

14 In case of  $|IV - IV2D| \leq TH$   $IV \leftarrow IV$

15 where  $\gamma$  is a constant ( $0 < \gamma < 1$ ).

16 That is, in case where the established vanishing point  
 17 IV is larger than the vanishing point IV2D identified from the  
 18 left and right lane markers in the image, this case means that  
 19 the established vanishing point IV deviates rightward in the  
 20 horizontal direction of the image. In this case, the established  
 21 vanishing point IV is shifted leftward by a specified amount by  
 22 subtracting the constant  $\gamma$  from the present value of the  
 23 established vanishing point IV. On the other hand, in case where  
 24 the established vanishing point IV is smaller than the vanishing  
 25 point IV2D, this case means that the established vanishing point

1 IV deviates leftward in the horizontal direction of the image.  
 2 In this case, the established vanishing point IV is shifted  
 3 rightward by a specified amount by adding the constant  $\gamma$  to the  
 4 present value of the established vanishing point IV. Further,  
 5 in order to make the control stable, in case where the difference  
 6 (absolute value) between both is within a specified value TH,  
 7 the established vanishing point IV is not changed.

8 Similarly, the vanishing point JV is updated according  
 9 to the following proportional control by comparing the present  
 10 value of the j coordinate value JV of the established vanishing  
 11 point V with the j coordinate value JV2D of the calculated  
 12 vanishing point V2d.

13 [Updating of vanishing point JV]

14 In case of  $JV - JV2D > TH$   $JV \leftarrow JV - \delta$

15 In case of  $JV - JV2D < -TH$   $JV \leftarrow JV + \delta$

16 In case of  $|JV - JV2D| \leq TH$   $JV \leftarrow JV$

17 where  $\delta$  is a constant ( $0 < \delta < 1$ ).

18 That is, in case where the established vanishing point  
 19 JV is larger than the vanishing point JV2D identified from the  
 20 left and right lane markers in the image, this case means that  
 21 the established vanishing point JV deviates upward in the vertical  
 22 direction of the image. In this case, the established vanishing  
 23 point JV is shifted downward by a specified amount by subtracting  
 24 the constant  $\delta$  from the present value of the established  
 25 vanishing point JV. On the other hand, in case where the

1 established vanishing point JV is smaller than the vanishing point  
2 JV2D, this case means that the established vanishing point JV  
3 deviates downward in the vertical direction of the image. In this  
4 case, the established vanishing point JV is shifted upward by  
5 a specified amount by adding the constant  $\delta$  to the present value  
6 of the established vanishing point JV. Further, in order to make  
7 the control stable, in case where the difference (absolute value)  
8 between both is within a specified value TH, the established  
9 vanishing point JV is not changed.

10 At a step 54 following the step 53, the vanishing point  
11 V (IV, JV) is outputted to the recognition section 10.

12 When the established vanishing point (IV, JV) is not  
13 proper, that value gradually comes close to a proper value by  
14 carrying out the aforesaid flowchart in each cycle. Specifically,  
15 this flow of control is performed in real time in parallel with  
16 the normal monitoring control and even when errors are caused  
17 in the present value of the established vanishing point (IV, JV),  
18 that value containing errors gradually converges to an optimum  
19 value. As a result, the position (X, Y) of an object can be  
20 calculated with high precision, thereby the reliability of  
21 vehicle surroundings monitoring can be enhanced.

22 [Application to miscellaneous monitoring apparatuses]

23 In the embodiments described before, the method of  
24 calculating the vanishing point using the left and right lane  
25 markers projected on the image has been explained. This method

1 is based on a general tendency that, in case of monitoring ahead  
2 of the vehicle, there exist lane markers extending in the front  
3 (depth) direction of the vehicle on left and right sides of the  
4 road and these lane markers are parallel with each other. In the  
5 specification, a linear object like lane markers which extend  
6 in the front direction in parallel with each other, and which  
7 is a base for calculating an vanishing point, is referred to as  
8 "reference object". The present invention can be broadly applied  
9 to miscellaneous monitoring system using picture images where  
10 the "reference object" is projected.

11 Taking an example, in case of applying to an indoor  
12 robot able to recognize surrounding situations, a boundary line  
13 constituted by a wall and a floor can be used as a "reference  
14 object". Fig. 16 is an example of an image taken by an indoor  
15 robot. Normally, in many cases, the boundary line of a left wall  
16 and a floor and the boundary line of a right wall and a floor  
17 extend in the depth direction of the image in parallel with each  
18 other. Accordingly, the correction of the vanishing point or the  
19 correction of distance can be done by using the left and right  
20 boundary lines.

21 Below, the outline of steps for adjusting the vanishing  
22 point making use of boundary lines.

23 First, a plurality of lines L1, L2 are detected based  
24 on the reference image. In the same way as the condition of white  
25 line edges described before, conditions with respect to

1 brightness edges or parallax at the boundary portion between wall  
2 and floor are established before hand. Further, portions  
3 satisfying these conditions are recognized as boundary lines in  
4 the image and the linearity of these boundary lines is evaluated.  
5 After these processes, approximation lines L1, L2 are calculated.  
6 In another way, lines L1, L2 as "reference object" may be  
7 calculated by extracting dots (edge pixels at boundary portions)  
8 for forming lines in the image, using well-known Huff  
9 transformation and the like.

10 Next, it is judged that the lines L1, L2 are  
11 approximately parallel with each other based on the distance image.  
12 As described before, the position of respective areas  
13 constituting lines L1, L2 in real space can be identified based  
14 on the distance image. Accordingly, in case where two lines L1,  
15 L2 are detected, the parallelism of these lines L1, L2 is judged  
16 using the known method.

17 In case where the lines L1, L2 are parallel, a vanishing  
18 point is calculated from the point of intersection of these lines  
19 L1, L2. Further, a gradient  $a$  of lines L1, L2 is calculated  
20 respectively and coordinates of the vanishing point are  
21 calculated based on the gradient. Finally, the value of the  
22 vanishing point parallax is adjusted such that the coordinates  
23 of two calculated vanishing points agree with each other.

24 Further, taking another example, in case of applying  
25 to the system for monitoring frontal situations of a railway



1 rolling stock, left and right railways can be utilized as  
2 "reference object". Fig. 17 is an example of the image projecting  
3 the front scenery of the railway rolling stock. The left and right  
4 railways extend in the depth direction in parallel with each other.  
5 Accordingly, two parallel lines L1, L2 can be identified by making  
6 use of the left and right railways as "reference object", thereby  
7 the vanishing points can be adjusted by the method described  
8 above.

9 In summary, according to the present invention,  
10 parameters with respect to the calculation of three-dimensional  
11 information such as distance information, for example, a  
12 vanishing point parallax DP, an affine parameter SHFTI, a  
13 vanishing point (IV, JV) and the like, are corrected based on  
14 the actual vanishing point calculated from the left and right  
15 lane markers in the image. Accordingly, in case where a positional  
16 deviation of the stereoscopic camera occurs, since the parameters  
17 values are automatically adjusted so as to offset errors caused  
18 by that positional deviation, three-dimensional information (for  
19 example, distance information) with high accuracy can be obtained  
20 stably.

21 While the presently preferred embodiments of the  
22 present invention have been shown and described, it is to be  
23 understood that these disclosures are for the purpose of  
24 illustration and that various changes and modifications may be  
25 made without departing from the scope of the invention as set

1 forth in the appended claims.

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